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Design of A Reconfigurable Spherical Robot II

Natthaphon Bunathuek [1] and Phongsatorn Saisutjarit [2] and Pudit Laksanacharoen [3]
Mechanical and Aerospace Engineering Department
King Mongkut University of Technology North Bangkok
Bangkok, 10800 THAILAND
email: nbt_09@hotmail.com [1] , pomastro@gmail.com [2], doctornoom@gmail.com [3]

[1] ***Abstract*— This paper describes the design of a three-legged reconfigurable spherical robot II. The reconfigurable spherical robot II is designed with the ability to transform from a spherical shape into a configuration of two interconnected hemispheres and three legs which are kept inside the shells can be extended to provide mobility on ground. The reconfigurable spherical robot II introduced a new method of leg deployment which reduced the amount of joint torques. Each leg is designed with 4 degrees of freedom for better maneuverability. The development of a butterfly walking concept using three-legged was presented. A dynamic simulation in MATLAB has been developed to predict loads and to verify the mobility of three-legged butterfly walking concept.**

I. Introduction

Robotic technology has gained more attention to human activities, for example, performing hazardous tasks such as search and rescue, exploring uncharted space. The recent robot design focuses on its flexibility and durability for working in unknown environments.

In our previous work [1], [2], [3], [4] we introduced a novel robot design that can be reconfigured into two interconnected hemispheres with three legs extension.

When the robot was packed in spherical shape, it provided versatile packaging for storage and transporation. Due to its limitation of maneuverability of the spherical robot, this robot was designed to be reconfigurable into a mobile platform with two interconnected hemispheres and three legged-wheels.

Each leg is designed with four degrees of freedom with passive omni-directional wheel at the tip of the leg. The leg deployment had also been redesigned to use less amount of joint torques. The actuators, sensors and control systems are packed inside the spherical shape. The spherical robot II still needs to be tethered for external power.

The dynamic simulation using MATLAB for three-legged walking inspired by the butterfly walking concept [5] was perfomed in this reconfigurable spherical robot II.

II. Background

A number of robotic research studies have been done on constructing a spherical robot rolling on a plane. The locomotion of the spherical robot are mostly propelled by an internal mechanism with a single wheel resting on the bottom of the spherical shell [6], [7], [8].

A design proposed by Alves et al. [9] utilized the movement of the center of gravity of the spherical shell for steering. Koshiyama and Yamafuji [10] proposed a spherical robot design used two internal pendulums for moving its center of gravity.

Previous discussions on the steering mechanisms of the spherical robots illustrate the drawbacks of this design: the control algorithm is highly complex, and the maneuverability is limited by the steering procedure.

This paper presents a reconfigurable spherical robot II which is a continuous work on a reconfigurable spherical robot I developed at King Mongkut University of Technology North Bangkok in Thailand. The reconfigurable spherical robot I can transform into two interconnected hemispheres with three legs where each leg has one degree of freedom for leg deployment. The leg deployment process required a high amount of joint torques.

The reconfigurable spherical robot II can also transform into two interconnected hemispheres with three legs where each leg is now designed with four degrees of freedom. The current concept of leg deployment is biologically inspired by human arm extension.

III. Conceptual Design

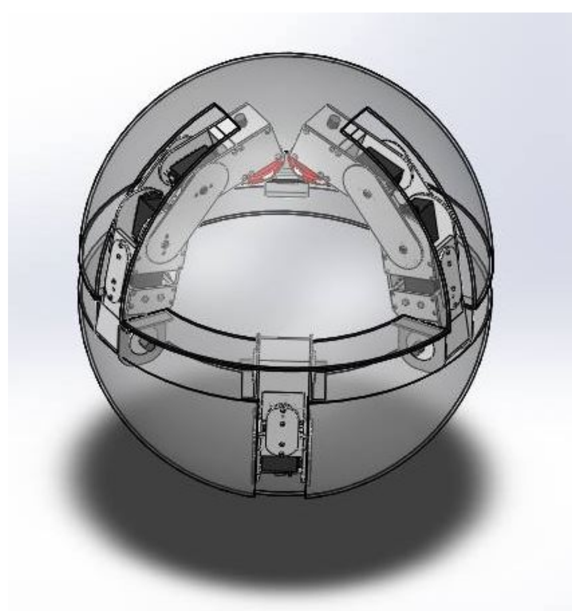

Fig. 1. Design of Reconfigurable Spherical Robot II

[1]Pudit Laksanacharoen was previously named Sathaporn Laksanacharoen

The design of reconfigurable spherical robot II consists of two hemispherical shells and three legs kept inside similar to reconfigurable spherical robot I. When the robot is in its dormant form, it is in the spherical shape as shown in Fig 1.

The outer spherical shells are made of fiberglass to strengthen its structure with a diameter of 350 mm. The fully stretched length of the robot leg is shown in Fig 2 and Fig 3 The omnidirectional wheel has a radius of 50 mm.

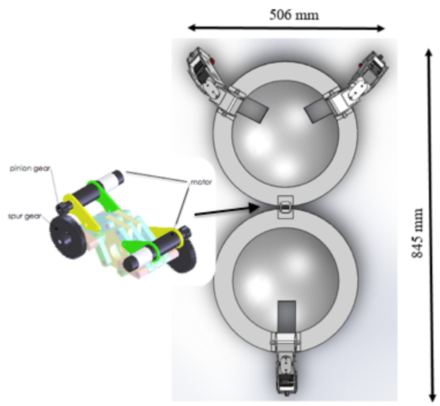

Fig. 2. Design of Reconfigurable Spherical Robot II

The reconfigurable spherical robot II has three omni-directional wheels passived. The previous design for leg deployment was required that each leg has to raised up in the air then drop down to the ground [2] with only one motor requirement. Therefore, it was required a hight amount of joint torques for leg deployment.

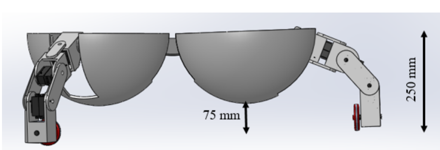

Fig. 3. Design of Reconfigurable Spherical Robot II

The new conceptual design for leg deployment was biologically inspired by human arm extension when the leg was contracted the leg was simply contracted and kept inside the spherical shell. When the legs extended, they simply extracted from its shell which imitate elbow joint and wrist joint movement in human arm as shown in Fig 4.

For simplicity, all three legs have the same configuration. There are a total of 4 motors on each leg: 2 motors for shoulder/hip joint, 1 motor/degree of freedom for elbow, and 1 motor/degree of freedom for wrist joint. Each leg is attached to the edge of hemispherical shell. The transformation process is driven by a motor at each joint. When fully transformed, the robot leg should be able to provide standing on ground and move with the butterfly walking concept.

Fig. 4. Leg deployment conceptual design

IV. Kinematic Model

Each leg is modeled as a 4 R type robot arm with the joint 1 attached to the hemispherical shell as shown in Fig 5.

The D-H parameters for each leg are shown in Table I

TABLE I
D-H PARAMETERS

No.	α_i	a_i	d_j	θ_i
1	$-\frac{\pi}{2}$	L1	0	θ_1
2	$\frac{\pi}{2}$	L2	0	θ_2
3	0	L3	0	θ_3
4	0	L4	0	θ_4

Transformation operators can be written as

$$T_{01} = \begin{bmatrix} \cos\theta_1 & 0 & -\sin\theta_1 & L_1\cos\theta_1 \\ \sin\theta_1 & 0 & \cos\theta_1 & L_1\sin\theta_1 \\ & -1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$T_{12} = \begin{bmatrix} \cos\theta_2 & 0 & -\sin\theta_2 & L_2\cos\theta_2 \\ \sin\theta_2 & 0 & \cos\theta_2 & L_2\sin\theta_2 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$T_{23} = \begin{bmatrix} \cos\theta_3 & 0 & -\sin\theta_3 & L_3\cos\theta_3 \\ \sin\theta_3 & 0 & \cos\theta_3 & L_3\sin\theta_3 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$T_{34} = \begin{bmatrix} \cos\theta_4 & 0 & -\sin\theta_4 & L_4\cos\theta_4 \\ \sin\theta_4 & 0 & \cos\theta_4 & L_4\sin\theta_4 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

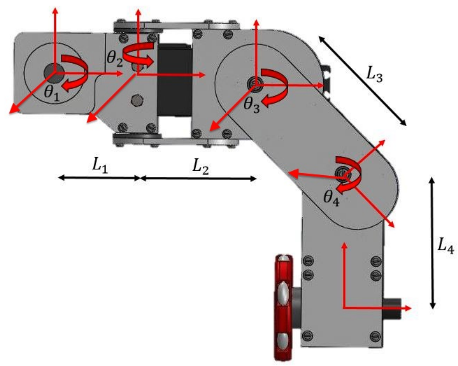

Fig. 5. Leg kinematics

V. CONTROL HARDWARE AND ACTUATORS

The control system consists of Arduino MEGA 1280 controller board. A total of 14 motors are 5 MAXON DC RE13 (3 watt 24V) and 9 servo motors HITEC HSR-5980SG (30 kg.cm 5V). Two MAXON DC motors drive at the hinged joint of two interconnected hemispheres to open/close the two hemispherical shells. Three MAXON DC motors attached at the connecting joint 1 between hemispheres body and leg are for leg deployment. The 3 HITEC HSR servo motors are chosen to drive for each leg segment.

The input signals are IR sensor (SHARP 2Y0A21) and limit switch. The limit switch is used to sense its open/close hemispheres during the transformation. The IR sensor is used to detect for obstacle avoidance.

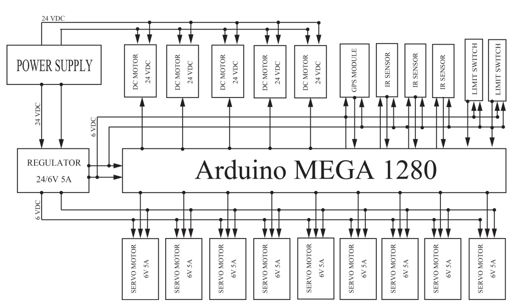

Fig. 6. Control Diagram

VI. EXPERIMENTAL RESULTS

A. Dynamic Simulation

Dynamic simulation of the transformation process was done with MATLAB. The concept of transformation was assumed that the robot transformed from a spherical shape into a two interconnected hemispheres.

The transformation process is shown in Fig 7 with the assumption that the ground contact was modeled as a PD controller [11].

Fig 8, 9, 10 show the amount of torque during the transformation process of right leg, left leg and back leg respectively.

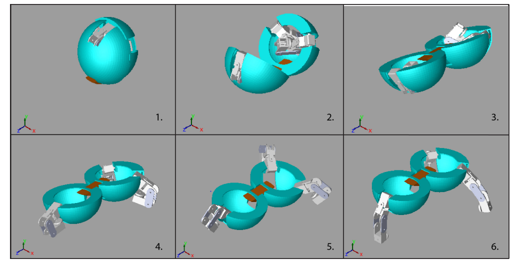

Fig. 7. Transformation process

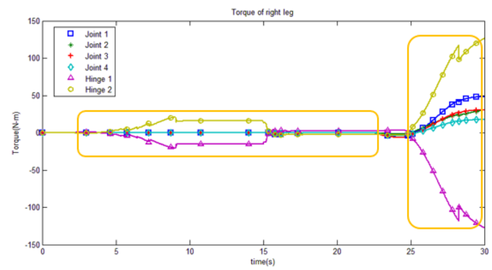

Fig. 8. Transformation Process of right leg

The highest amount of torque occur at joint 1 of the back leg is about 150 N-m which is related to the fact that the back leg only has one support for the hemisphere. The other two left and right leg have the maximum around 50 N-m. Two motors; hinge 1 and 2, drive the two interconnected hemispheres to open during the transformation process.

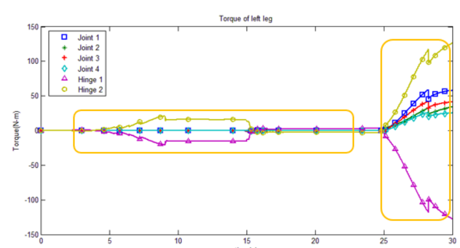

Fig. 9. Transformation Process of left leg

To ensure statically stable walking, it is required at a minimum of three legs for walking robots. This work proposed the three legs walking inspired by the butterfly walking concept. While a pair of front legs lift off the ground, the lowest part of its hemisphere helps support for stable walking until both front legs touch the ground to push and lift its body for moving forward. One back leg pushed to drive the robot moving forward.

The dynamic simulation results of three-legged walking inspired by the butterfly walking concept is shown in Fig 11.

Fig 12 shows one front leg trajectory which correspond to the graph shown in Fig 13 and 14. The back leg shown in Fig 15 gives the pushing force for the robot to move forward. This leg movement creates the butterfly walking motion.

The joint 1 which was attached to the body of each leg

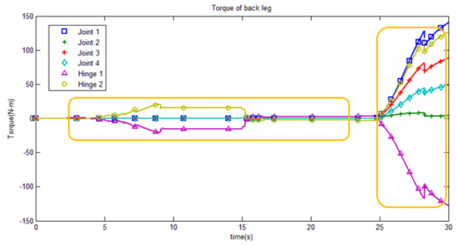

Fig. 10. Transformation Process of back leg

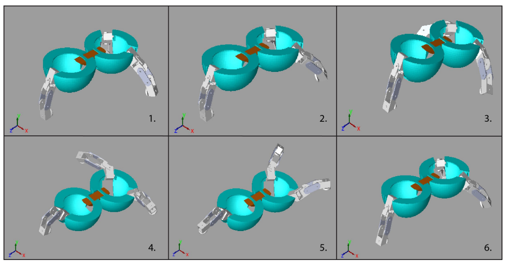

Fig. 11. Butterfly Walking Simulation

required the maximum amount of torque. The highest amount of torque occurs during the pushing of the back leg at about 200 N-m.

B. Robot Experiment

The weight of the robot is about 5.0 kg. The reconfigurable spherical robot II was developed and tested for the transformation process as shown in Fig 16 and leg deployment concept was shown in Fig 17.

The locomotion on the robot using concept of butterfly walking was shown in Fig 18. The robot was tethered and hanging on the poles to help its support during the butterfly walking concept We hope to implement the untethered butterfly walking concept in the near future.

VII. Conclusion

Design and development of a reconfigurable spherical robot II has been demonstrated in the paper. The spherical robot can be reconfigured into two interconnected hemispheres with three legs deployment process based on biologically human arm extension. The reconfigurable spherical robot II shows butterfly walking concept for three legs in simulation results as well as on the robot.

Acknowledgment

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References

[1] N. Chadil, M. Phadoongsidhi, K. Suwannasit, P. Manoonpong, and P. Laksanacharoen, "A reconfigurable spherical robot," in *2011 IEEE International Conference on Robotics and Automation (ICRA2011)*, Shanghai, China, May 9-13 2011.

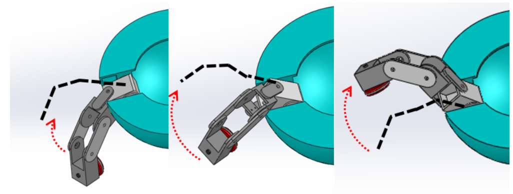

Fig. 12. Butterfly walking leg movement

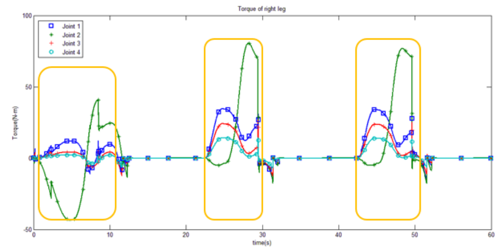

Fig. 13. Butterfly walking Right Leg

[2] P. Jearanaisilawong, S. Laksanacharoen, V. Piriyawong, and K. Swatdipisal, "Design of a three-legged reconfigurable spherical shape robot," in *2009 IEEE/ASME International Conference on Advanced Intelligent Mechatronics(AIM2009)*, Suntec Convention and Exhibition Center, Singapore, July 14-16 2009.

[3] P. Jearanaisilawong and S. Laksanacharoen, "Dynamic simulation of a reconfigurable spherical robot," in *Proceedings of the 2008 IEEE International Conference on Robotics and Biomimetics(Robio2008)*, Bangkok, Thailand, February 21-26 2009.

[4] F. W. Poramate Manoonpong and P. Laksanacharoen, "Biologically inspired modular neural control for a leg-wheel hybrid robot," *Advances in Robotics Research*, vol. 1, no. 1, pp. 101–126, 2014.

[5] J. Tanaka, S. Chigisaki, S. Hirose, and S. Laksanacharoen, "Study of an amphibious leg-wheel hybrid mobile robot, ferret (development of a butterfly walking first prototype)," in *The Society of Instrument and Control Engineers SI 2007 in Japanese*, Hiroshima, Japan, December 20-22 2007.

[6] A. Halme, T. Schonberg, and Y. Wang, "Motion control of a spherical mobile robot," in *Proc. 4th International Workshop on Advanced Motion Control*, Tsu, Japan, 1996.

[7] A. Halme, J. Suomela, T. Schonberg, and Y. Wang, "A spherical mobile micro-robot for scientific applications," in *Proceedings of the 4th ESA Workshop on ASTRA Noordwijk: The European Space Agency*, 1996.

[8] F. Michaud and S. Caron, "Roball, the rolling robot," *Autonomous Robots*, vol. 12, pp. 211–222, 2002.

[9] J. Alves and J. Dias, "Design and control of a spherical mobile robot," in *International Conference on Mechatronics 2003 (ICOM2003)*, Leicestershire, UK, June 2003.

[10] A. Koshiyaya and K. Yamafuji, "Design and control of an all-direction sterring type mobile robot," *Int. J. Robotics Res*, vol. 12, no. 5, pp. 411–419, 1993.

[11] X. Bajrami, A. Shala, R. Likaj, and A. Dermaku, "Modeling of a humanoid robot archie," *International Journal of Current Engineering and Technology*, vol. 3, no. 3, pp. 867–871, 2013.

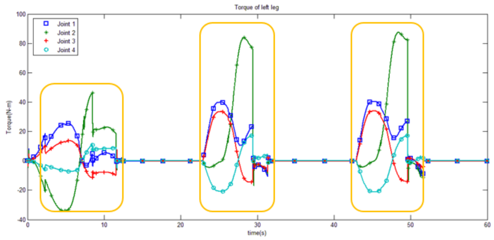

Fig. 14. Butterfly walking Left leg

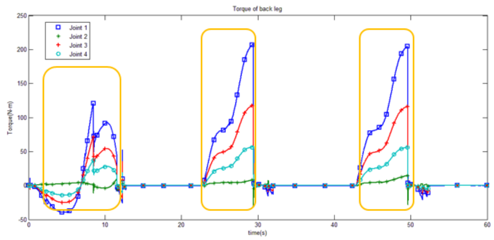

Fig. 15. Butterfly walking Back leg

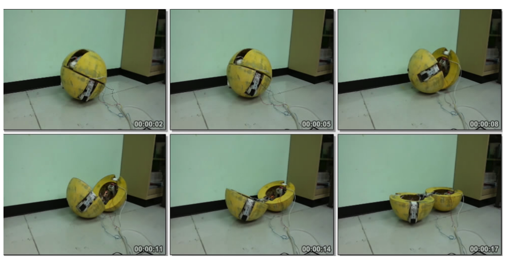

Fig. 16. Transformation process of reconfigurable spherical robot

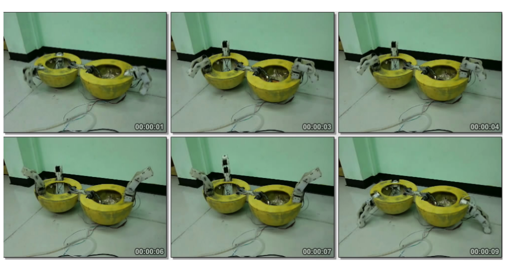

Fig. 17. Leg deployment

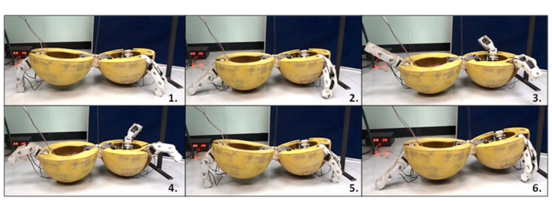

Fig. 18. Butterfly walking concept (tethered)